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13. ABSTRACT *(Maximum 200 Words)*

A mobile optical observatory was established at the Plasma Science and Fusion Center on campus at MIT. It consists of an All Sky Imaging System (ASIS) and a pick-up truck with a camper-like-box. The major components of ASIS includes : (1) all-sky lenses with different fields of view (FoV) [i.e., 24mm/F4.0 fish-eye -180 deg. FoV, 45mm/F2.8 - 76 deg. FoV, and 210mm / F4.0 - 19 deg. FoV], (2) narrow-band interference spectral filters, (3) 2- and 3-log neutral density filters, (4) image intensifier unit, (5) cooled CCD camera, and (6) data acquisition and remote controlling systems. ASIS is a powerful instruments for atmospheric plasma diagnostics. For example, in radio wave injection and chemical release experiments, rich information can be deduced from the measured airglow. The images of highly structured plasma clouds in chemical release experiments will help identify the source mechanisms, producing plasma density irregularities. Measured intensity of airglow emissions (at 630.0 nm) in radio wave injection experiments will show plasma density depletion. Emissions may also be based on estimating the fluxes of generated energetic particles (at 427.8 nm in E region and at 630.0 nm in F region), neutral wind (at 557.7 nm), and plasma drifts (at 777.4 nm).

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All Sky Imaging System for Atmospheric Plasma Diagnostics

1. Introduction

A mobile optical observatory was established at the Plasma Science and Fusion Center on campus at the Massachusetts Institute of Technology under the Defense University Research Instrumentation Program grant AFOSR F49620-02-1-0222. It consists of an All Sky Imaging System (ASIS) and a pick-up truck with a camper-like-box. The All Sky Imaging System was built by Keo Consultant (Brookline, Massachusetts), having the following major components: (1) all-sky lenses with different fields of view, (2) narrow-band interference spectral filters, (3) 2- and 3-log neutral density filters, (4) image intensifier unit, (5) cooled CCD camera, and (6) data acquisition and remote controlling systems. A photograph of the All Sky Imaging System is shown in Figure 1.

An all-sky lens with 180 deg. (fish-eye) field of view is ideal for collection of emissions from a large area of sky in radio wave injection experiments. However, a lens with much smaller field of view (e.g., 76 deg. and 19 deg.) can be used to detect emissions from a narrow region in, for example, chemical release experiments and laboratory plasma experiments. Spectral filters are selected for emission features related to investigated ionospheric structures and processes. Monochromatic measurements at high sensitivity (e,g., 20 Rayleighs) is desirable for obtaining both spatial and temperal data, to identify source mechanisms responsible for exciting the optical emissions. Very narrow (typically, 1.5 - 2 nm) interference filters are used, because the extreme optical rays at large zenith angles lack convergence. The use of image intensifiers is to achieve the high sensitivity of, e.g., 20 Rayleighs.

Since the image intensifier tube can be damaged by bright light (namely, sunlight and moonlight), the ASIS will be operated primarily during completely dark nights. However, in chemical release experiments, atoms need to be injected into the upper atmosphere, under conditions such that the cloud of atoms is sunlit fully, but the sky is dark enough for optical observations. This is because that, while the sunlight can ionize the atoms, it can also make the ionized atoms visible via a resonant scattering process. Thus, neutral density (ND) filters together with spectral filters are placed

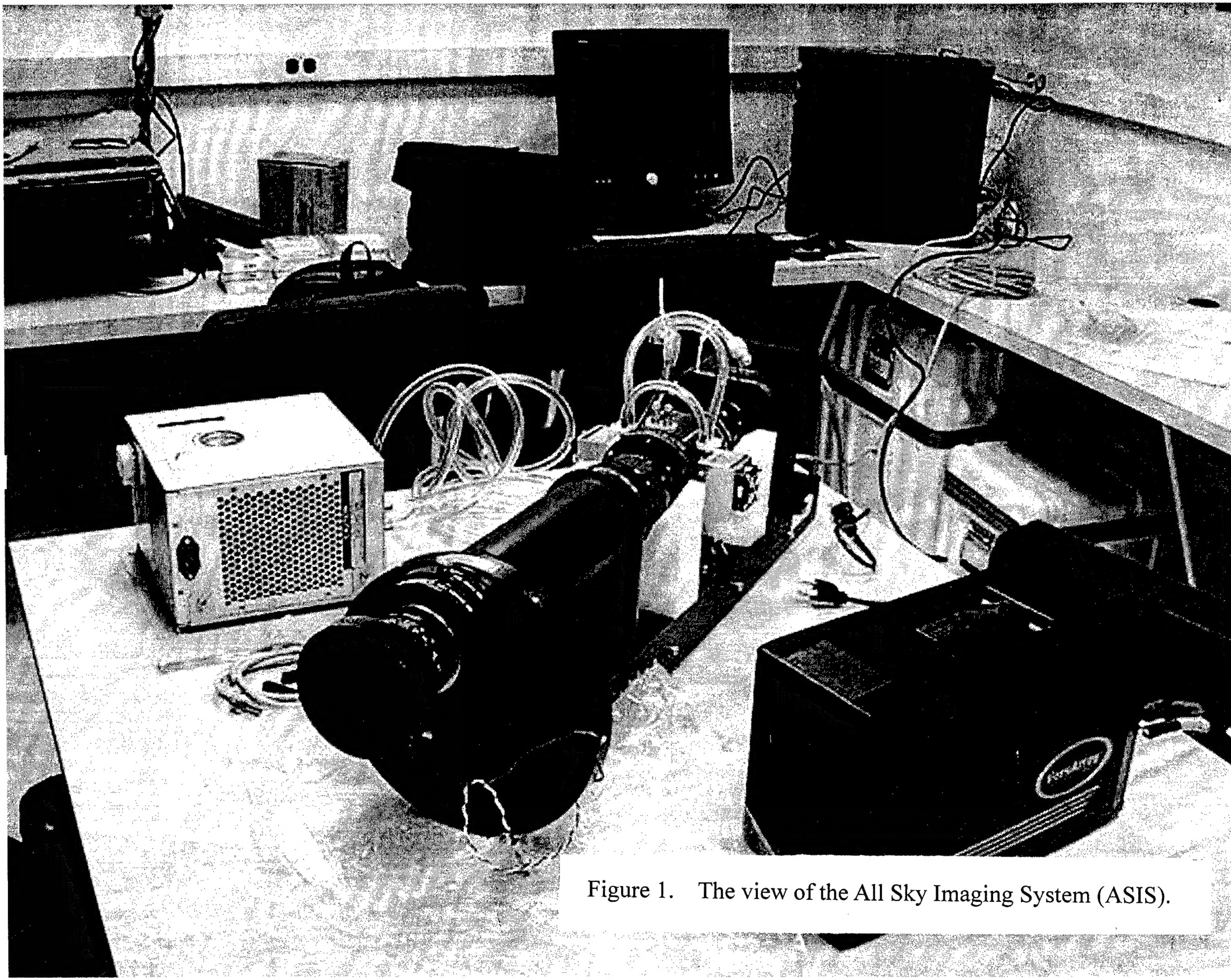

Figure 1. The view of the All Sky Imaging System (ASIS).

between the all-sky lens and the CCD camera to protect the sensitive intensifier unit. Data are, then, recorded by the cooled CCD camera as either monochromatic, photographic images or video signals using a TV system, at an adjustable integration time and intensifier gain, setting as determined by the bright features. To deploy the All Sky Imaging System (ASIS) easily for experiments, our truck has a removable camper-like box, which can be left at the experimental site as an optical observatory, while the truck can still be used for shipping and transportation.

2. Operation of ASIS

A brief description of how to operate the All Sky Imaging System (ASIS) is given here. ASIS has a primary lens that images the sky telecentrically through filters in a six-position filter wheel containing narrow-band interference filters (for 777.4 nm, 733.3 nm, 630.0 nm, 557.7 nm, 467.5 nm and 427.8 nm). Three primary lenses are designed for different experimental conditions, each with its own telecentric lens elements. They are (1) 24mm / F4.0 fish-eye - 180 deg. field of view (FoV), (2) 45mm / F2.8 - 76 deg. FoV, and (3) 210mm / F4.0 - 19 deg. FoV. The center wavelength of some types of interference filters is temperature dependent. A stand-alone proportional temperature controller is provided with the ASIS to keep the temperature of the filters at approximately room temperature. The temperature can be controlled remotely via a standard serial interface.

The primary image is then re-imaged either onto the front of a image intensifier or directly onto the CCD chip. Gain control of the image intensifier allows controlling the gain. If the intensifier is used (Figure 2), the output image is then re-imaged onto the CCD of the CCD camera head. The camera head is thermo-electrically cooled to provide a decreased dark-noise accumulation and allow longer integration times. In addition, there is a liquid-cooling assist option, where water or glycol is circulated with the liquid circulation unit provided. Liquid cooling is also provided for the image intensifier cooler. The liquid lines to the camera and intensifier cooler may be connected in series, in parallel, or independently.

The CCD camera head is connected to the camera electronics unit which supplies power, timing signals and the data interface both to the camera head and back to the host computer. The camera electronics unit has

Image Intensifer Mode

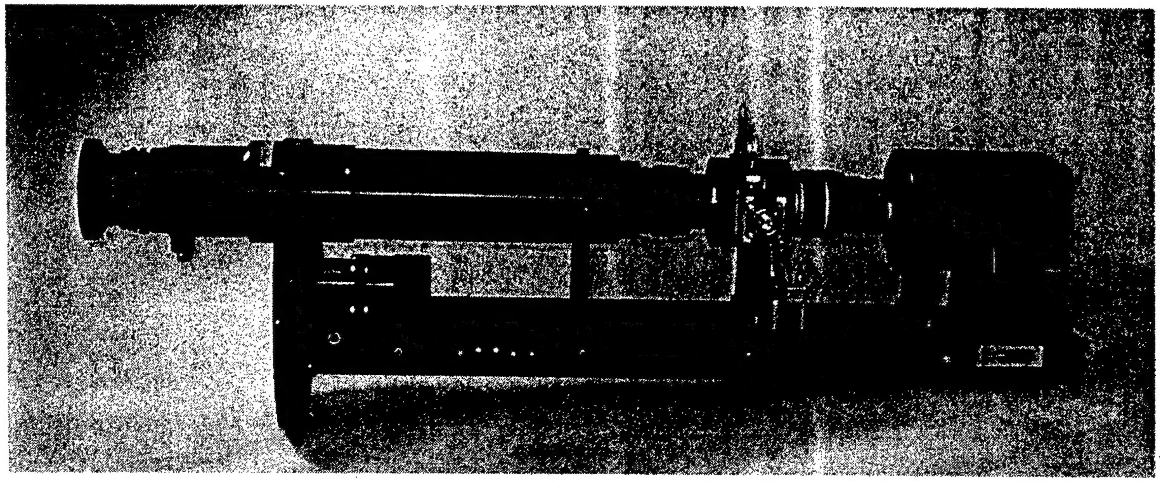

Figure 2. An image intensifier used with the CCD camera.

Bare CCD Mode

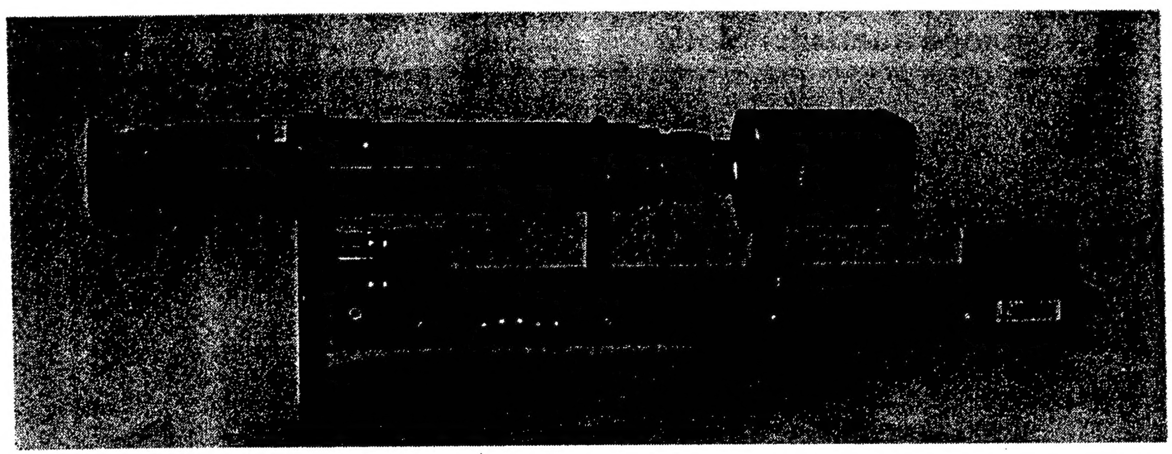

Figure 3. CCD camera without the intensifier.

capability of dual-speed conversion. When using the image intensifier, the fast conversion should be used, and when using the bare CCD (Figure 3), the slow conversion should be used. The camera head has an internal shutter directly in front of the CCD window which is used for the exposure time.

A shutter at the front of the ASIS is used as a capping shutter (sunlight directly hitting the interference filters can damage them). A light detector at the front of ASIS is used as an automatic over-ride to avoid over-exposure and possible damage to the image intensifier. A standard serial interface is used to control the filter wheel, intensifier and shutter operations.

3. Calibration of ASIS

A light source manufactured by Gamma Scientific (San Diego, California) is currently used to calibrate ASIS. Several calibration processes are briefly described below.

(A) CCD Bias (Read Noise)

The CCD bias (read noise) is the number of counts associated with CCD read electronics. This is the base value gotten with a CCD readout with absolutely no photoelectrons collected in the pixels. This value is, thus, independent of exposure time and so is a constant that can be subtracted out of every image. The CCD bias is incorporated into the read electronics and is intrinsic to the actual electronics. A bias is necessary to bias the analog electronics zero point above the 0 reference point for the Analog-Digital-Converter (ADC). This can ensure that no photoelectrons are lost due to a negative bias. It is desirable to look at this value periodically and to store a bias image at the beginning and end of each data acquisition period. Bias images can provide information on the state of the CCD read electronics and help track the health of this component of ASIS.

Bias measurements are taken with the intensifier and shutter turned off and a dark environment to protect against light-leak photons getting to the CCD surface. Bias measurements require that the CCD is cleared several times. Right after clearing the CCD, a CCD_READ takes place. This ensures not only no counting of any photoelectrons from light-leaks etc, but also no

counting of any dark-noise associated electrons [see Section (B) below].

(B) Dark Noises

Basically, there are two dark-noise contributions in ASIS. One is the purely the dark-noise contribution of the actual CCD chip itself. The CCD chip is cooled to about 65° C below ambient (typically set to -40° C). A CCD in a completely dark environment will generate thermal noise and accumulate this noise in the pixels until the CCD is cleared again. In bare-CCD mode, CCD-noise will become a contribution for long exposures trying to get faint atmospheric emissions. Measuring the CCD dark noise is therefore very important based on two parameters: CCD temperature and exposure time.

Taking CCD dark-noise images without any image intensifier power and a series of exposures at a few key temperatures (e.g., -20° C, -30° C, and -40° C) allow one to build up a good table of values. These values can then be subtracted from images based on experimental conditions.

When using the imager with the image intensifier, the imager intensifier also contributes dark noise (much more significant than the CCD as described earlier). Thermal electrons generated at the photocathode get accelerated down the image intensifier and are seen as significant bursts of light by the CCD. As such they depend on the gain setting of the image intensifier. For example, the average counts measured with the intensifier on for one second, the shutter closed, and the removal of the CCD bias are 11.16 (for Gain 0), 125.96 (Gain 1), and 1147.72 (Gain 2).

(C) Counts to Rayleigh Units

The aforementioned measure counts need to be converted to the Rayleigh units, which are the desired scientific units of measure of energy form optical observations. With the light source described above, measurements are done to derive a calibration chart describing ASIS' response to light at different wavelengths and intensifier gains. The measure counts are a function of filter wavelength, filter bandwidth, intensifier gain and exposure time. All values are normalized to unity exposure time of one second.

An example of calibrating ASIS radiometrically is to collect a series of good statistical images of the light source centered in the image. Then, take the

same exposures with the light source turn-off to get the exact background noise contributions (namely, CCD read noise + dark noise + intensifier noise + background light sources, etc.). Subtracting these two values to get an actual digital value of how many photons which ASIS has accumulated with the known light source.

(D) Vignetting and Spatial Calibration of ASIS

The main contribution to ASIS vignetting is the primary fish-eye lens. The light source is scanned from the center of the image to its edge [Figures 4]. A line plot of its intensity results in a linear equation to the first order characterizing the slope of intensity as a function of zenith angle. basically the light source is reduced linearly by a factor from overhead to the edge of the field of view.

A spatial calibration using starmaps will also be carried out to correct for azimuthal installation offsets and optical distortions, mostly attributed to the curvature of the lenses. From this one can derive the optical center of the image in pixel space and the radial mapping based upon best fit with the computer generated starmap.

4. ASIS as a New Diagnostic Instrument

ASIS will be an excellent complement to MIT's portable Ionospheric Radar Integrated System (IRIS) for atmospheric plasma diagnostics. For example, in radio wave injection and chemical release experiments, rich information can be deduced from the measured airglow. The images of highly structured plasma clouds in chemical release experiments will help identify the source mechanisms, producing plasma density irregularities. Measured intensity of airglow emissions (at 630.0 nm) in radio wave injection experiments will show plasma density depletion. Emissions may also be based on estimating the fluxes of generated energetic particles (at 427.8 nm in E region and at 630.0 nm in F region), neutral wind (at 557.7 nm), and plasma drifts (at 777.4 nm).

Furthermore, airglow measurements using ASIS can provide the optical evidence to support the radar-measured rising plasma bubbles [Lee et al., 1998(a)], large plasma density irregularity sheets [Lee et al., 1998(b); and

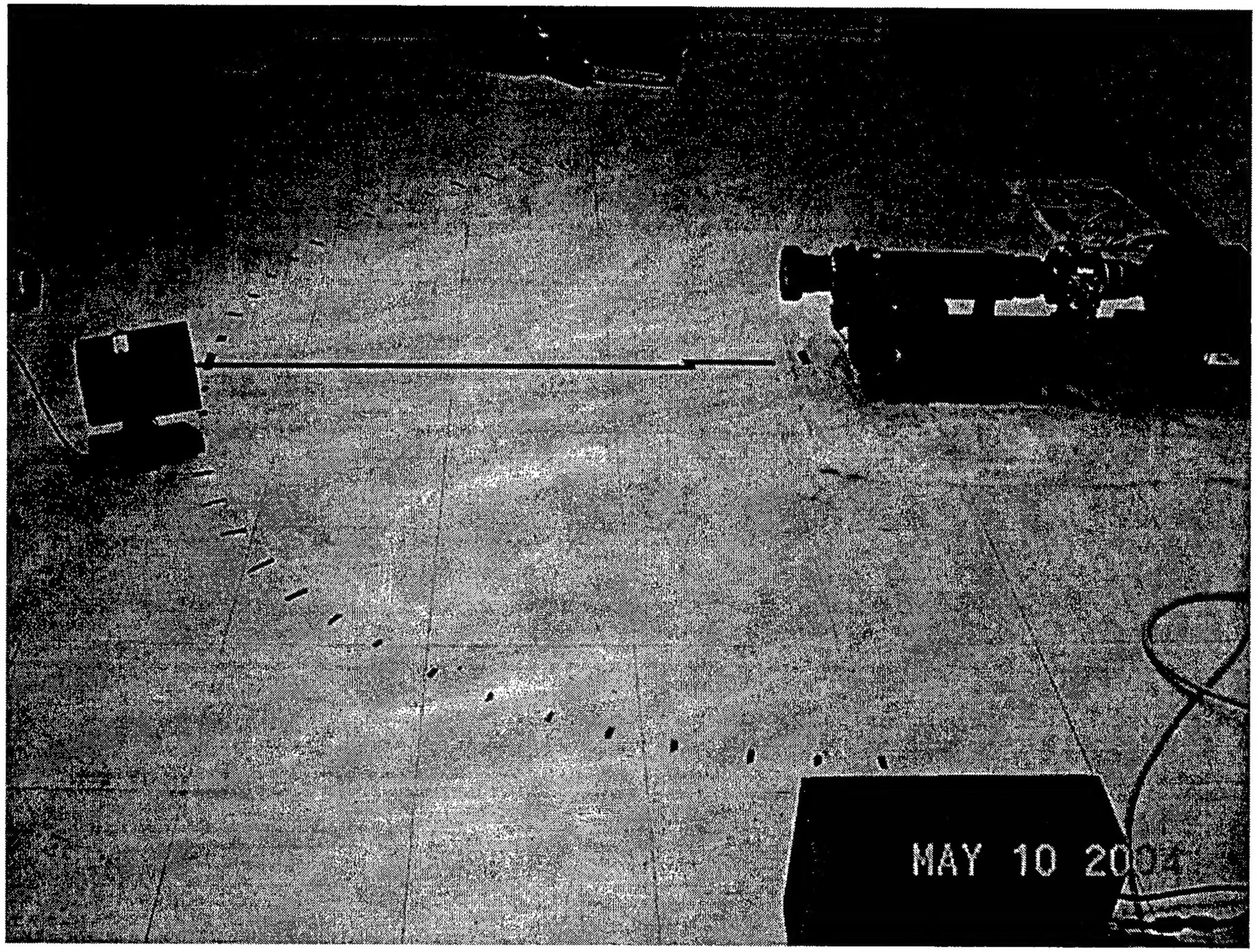

Figure 4. Light source scanned from the center of the image to its edge to analyze the vignetting of ASIS.

depleted magnetic flux tubes [Lee et al., 1999]. It is expected that the radar measurements of field-aligned plasma density irregularities can be cross-checked by optical measurements, especially, in the identification of source mechanisms associated with the drifting plasmas [Lee, 1984], irregularity shapes [Lee et al., 1989], plasma depletion [Lee et al., 1999], and artificial ionospheric ducts [Starks and Lee, 2000; Starks et al., 2001].

Finally, it should be mentioned that the Versatile Toroidal Facility (VTF) is a large plasma machine constructed by Principal Investigator's graduate students and UROP (Undergraduate Research Opportunities Program) students at MIT Plasma Science and Fusion Center (PSFC). VTF has been used to conduct laboratory simulations and successfully reproduced some Arecibo experimental results [Lee et al., 1997]. ASIS together with IRIS and VTF will greatly contribute to the integrated research and educational programs developed at PSFC, including theory, field experiments and laboratory simulation of radio wave propagation and interactions with space plasmas.

References

Lee, M.C., Ohmic dissipation of Pedersen current as the course of high-latitude F region ionospheric irregularities, Journal of Geophysical Research, 89, 7482, 1984.

Lee, M.C., S.V. Nghiem, and C. Yoo, Effects of irregularity anisotropy on Faraday polarization fluctuations, Journal of Geophysical Research, 94, 15421, 1989.

Lee, M.C., R.J. Riddolls, K.D. Vilece, N.E. Dalrymple, M.J. Rowlands, D.T. Moriarty, K. Groves, M.P. Sulzer, and S.P. Kuo, Laboratory reproduction of Arecibo experimental results: HF wave-enhanced Langmuir waves, Geophysical Research Letters, 24, 115, 1997.

Lee, M.C., R.J. Riddolls, W.J. Burke, M.P. Sulzer, E.M.C. Klien, M.J. Rowlands, and S.P. Kuo, Ionospheric plasma bubble generated by Arecibo heater, Geophysical Research Letters, 25, 579, 1998(a).

Lee, M.C., R.J. Riddolls, W.J. Burke, M.P. Sulzer, S.P. Kuo, and E.M.C. Klien, Generation of large sheet-like ionospheric plasma irregularities at Arecibo, Geophysical Research Letters, 25, 3067, 1998(b).

Lee, M.C., E.M.C. Klien, W.J. Burke, A.X. Zhang, R.. Riddolls, S.P. Kuo, M.P. Sulzer, and B. Isham, Augmentation of natural ionospheric plasma turbulence by HF heater waves, Geophysical Research Letters, 26, 37, 1999.

Starks, M.J. and M.C. Lee, Matched filtering for the measurement of conjugately ducted VLF transmissions, Radio Science, 35, 351, 2000.

Starks, M.J., M.C. Lee, and P. Jastrzebski, Interhemispheric propagation of VLF transmissions in the presence of ionospheric HF heating, Journal of Geophysical Research, 106, 5579, 2001.